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ABSTRACT

A study investigated the process of information extraction in reading in order to determine whether language constraints in texts reduced the amount of visual detail noticed by the reader during the reading of specific words. A detailed examination was made of 20 college students' eye movement patterns as they read a group of selected passages. The passages contained manipulations of word variables that involved interword redundancy and distorted spelling patterns. The results supported the claim that language constraint does affect the manner in which information in text is processed during reading and suggested that certain aspects of visual detail have a high degree of cognitive prominence. In essence, readers noticed specific letter information within a text segment being fixated, even in those instances when such detail was not needed for the identification of a specific word. (FL)

CENTER FOR THE STUDY OF READING

Technical Report No. 216

THE EFFECT OF REDUNDANCY ON THE PERCEPTION OF WORDS IN READING

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Abstract

The experimental investigation reported in this paper deals with the intriguing process of information extraction in reading. Specifically, the issues addressed concern the nature of the information that is selected by the reader during a visual focusing of attention upon a segment of printed language. Evidence was sought to determine whether or not language constraints in text reduce the amount of visual detail noticed during the reading of specific words. Most theories of reading suggest that an interaction between visual detail information and contextual information is indeed the mode of processing in conventional reading. A detailed examination was made of subjects' eye movement patterns that were recorded during the reading of a group of passages. The texts contained manipulations of word variables that involved interword redundancy and dis orted spelling patterns. The results support the claim that language constraint does affect the manner in which information in text is processed during reading, and suggest that certain aspects of visual detail have a high degree of cognitive prominence. In essence, readers are noticing specific letter information within the text segment being fixated even in those instances when such detail is not "needed" for the identification of a specific word.

The Effect of Redundancy on the Perception of Words in Reading

Does linguistic redundancy influence the perception of words during reading? If this is indeed the case, then how is the effect of this structural variable realized in the processing of the information contained in printed texts? These questions have motivated and continue to motivate a large number of research activities. It is quite often claimed that redundancy permits the interaction of two or more dimensions of stimulus information to provide better performance than that resulting from recognizing or noticing either source alone (e.g., Rumelhart, 1977). Such a fundamental assumption underlies most contemporary models of the reading process. For example, consider the encapsulated theoretical perspective offered by Smith (1971) in which readers are "regarded as 'predicting' their way through a passage of text, eliminating some alternatives in advance on the basis of their knowledge of the redundancy of language, and acquiring just enough visual information to eliminate the remaining alternatives" (p. 230). Such a position argues for a strong and dominant role for usage of the nongraphemic, contextual information contained in the structure of the prose being read.

This basic issue is important both theoretically and practically. From a theoretical point of view, one would like to understand just how a prior piece of constraining text, which by definition has the effect of reducing potential word alternatives, changes the process of information extraction. From a practical point of view, one would like to have some empirical evidence that could be used to evaluate alternative methods of reading instruction with respect to how the role of redundancy is treated.

The texts that people read are typically composed of grammatical and meaningful sequences of words. Printed words provide extremely rich sources of stimulus information. Every word represents some concrete or abstract object or event; i.e, words have meaning in the real world. But a word also contains information about pronunciation, spelling, grammatical function, and overall shape of visual pattern, to name only the more salient and obvious kinds of information (Gibson, 1974). Furthermore, when a word exists in isolation, it does not appear to represent a single entity or action, but rather a kind of generalization (Luria, 1970). In other words, when a particular word is presented alone (e.g., chair), it does not designate a single object, but rather, a variety of objects that have common properties. Recognition of a word depends upon the extraction of the kind or kinds of information necessary to fulfill the recognition task. Reading is the task where semantic information must be identified and extracted. It is often, however, the other kinds of information (for instance, letter and syntactic information) that are noticed.

In addition to these properties, words possess an internal and an external structure. The internal structure for English words arises from the conditional rule systems for spelling that are morphophonemic in nature (Gibson, 1974). For example, the letter combination gl is acceptable as an initial consonant cluster, but not as a final consonant cluster. The external structure arises from the syntactic and semantic relations that exist among words. For example, the selectional restrictions of a language ensure that only permissible grammatical and meaningful relationships can

occur between the words of an acceptable sentence (Elgin, 1973). These structural properties within and among language elements create predictable regularities that are referred to as redundancy.

Redundancy

The concept of redundancy and its related measurement methodology come from the field of communication and information theory (Shannon & Weaver, 1949). In general, redundancy is defined as any set of factors that reduces the number of alternatives from which a stimulus might be chosen. Therefore, redundancy is a measure of certainty. In the case of printed language, it is that set of factors which eliminates potential letter and word alternatives. Redundancy is spoken of in terms of its many and varied forms. For example, there is orthographic redundancy within the structure of words, and there is semantic redundancy among the elements of prose. The efficient reader takes advantage of the redundancies that exist in the continuous language of the material being read (Gibson, 1972; Gibson & Levin, 1975; Haber, 1978; Smith, 1971). The research task is to explicate the means by which this efficiency is achieved.

Context and the Perception of Language

There is a substantial body of research documenting the fact that the structural constraints of language facilitate the perception of language (Garner, 1962, 1974; Gibson, Pick, Osser, & Hammond, 1962; Miller, Bruner, & Postman, 1954; Miller & Isard, 1963; Miller & Selfridge, 1950; Morton, 1964b; Reicher, 1969; Wheeler, 1970).

One way to talk about the kinds of redundancy that are available in text is to speak of intraword and interword redundancy. Intraword redundancy refers to those regularities by which letters are combined to form words. As was mentioned above, these structural characteristics of words are best described by the phonological and orthographic rule systems. Extraction of information from words is facilitated by these invariant properties. The well-documented word-superiority phenomenon attests to this fact (Adams, 1979; Cattell, 1885/1947; Johnson, 1975). Interword redundancy, which is the focus of this paper, arises from the syntactic and semantic relations that can exist between and among words. The property of language that only permits certain grammatical constituents and semantic structures to exist is also a powerful factor influencing the extraction of information. The improved performance of word recognition in the presence of a verbal context provides good evidence for this position (Meyer & Schvaneveldt, 1971; Morton, 1964a; Pillsbury, 1897; Samuels, 1969; Tulving & Gold, 1963).

Those experiments that appear to be most directly concerned with the relationship between interword redundancy and visual perception in reading show that a verbal context provided by a sentence frame improves the accuracy and speed with which a word is recognized (Fischler & Bloom, 1979; Kleiman, 1977; Morton, 1964a; Pearson & Studt, 1975; Perfetti & Roth, 1981; Pollack, 1964; Schuberth & Eimas, 1977; Tulving & Gold, 1963; Tulving, Mandler, & Baumal, 1964; West & Stanovich, 1978). For illustrative purposes consider the seminal study by Tulving and Gold (1963) in which

sentence fragments (e.g., THE SKIERS WERE BURIED ALIVE BY THE SUDDEN . . .) provided the context for tachistoscopically-presented final nouns (e.g., AVALANCHE)/ visual duration thresholds for the correct identification of these nouns were lower (i.e., 27 msec faster) in the full-sentence context condition than in the no-context condition.

A similar phenomenon has also been reported in studies of auditory perceptibility (Marks & Miller, 1964; Marslen-Wilson & Welsh, 1978; Miller, Heise, & Lichten, 1951; Miller & Isard, 1963; Morton & Long, 1976; Slamecka, 1969; Stowe, Harris, & Hampton, 1963). Appropriate sentence contexts make anomalous or distorted words or sentences easier to hear and remember.

It is quite clear that even a single, related-word context facilitates word perceptibility. One group of studies has shown that presenting an associative word (e.g., black) just before a word to be identified (e.g., white) reduces the time required to make a veridical identification (Jacobson, 1973; O'Neil, 1953; Pillsbury, 1897; Rouse & Verinis, 1962; Samuels, 1970). Furthermore, in the past ten years, considerable attention has been devoted to studies that employ a lexical decision task. This new research has provided additional evidence that a single-word context can influence the speed and accuracy of discriminations (Antos, 1979; Becker, 1976; Becker & Killion, 1977; Coltheart, Davelaar, Jonasson, & Besner, 1977; Fischler, 1977a, 1977b; Fischler & Bloom, 1979; Fischler & Goodman, 1978; Forster & Chambers, 1973; James, 1975; Kleiman, 1977, 1979; Meyer & Schvaneveldt, 1971, 1976; Meyer, Schvaneveldt, Ruddy, 1974, 1975; Neely,

1976, 1977; Rubenstein, Garfield, & Millikan, 1970; Rubenstein, Lewis, & Rubenstein, 1971a, 1971b; Schvaneyeldt, Ackerman, & Semlear, 1977; Schvaneveldt & Meyer, 1973; Shulman & Davison, 1977; Tweedy, Lapinski, & Schvaneveldt, 1977). The basic nature of the experimental task involved in this line of research focuses upon the judgment of whether or not an alphabetic sequence is a word. The amount of time it takes for a subject to indicate that a target letter string is or is not a word provides an index of the speed of recognition, and is greatly influenced by the semantic nature of any immediately preceding word (e.g., to decide that the letter string NURSE is a word occurs approximately 85 msec faster if the word DOCTOR is presented just prior to the target string than if the word BREAD is presented).

There is an additional body of research that demonstrates the pervasive nature of enhanced perceptibility in the presence of a verbal context. The successive words of a piece of prose are subject to certain constraints imposed by the syntactic and semantic conventions of the language. A perceiver's ability to use these grammatical relations to facilitate the "pick up" of information from a segment of printed language is clearly documented in studies employing oral reading tasks (Biemiller, 1970; Goodman, 1969; Kolers, 1970; Sawyer, 1971; Weber, 1970), eye-voice span tasks (Levin & Kaplan, 1970; Morton, 1964b), anagram solution tasks (Gibson, Tenney, & Sharabany, 1971), and memorial tasks (Mehler, Bever, & Carey, 1967; Miller & Selfridge, 1950). The importance of this research is its demonstration of the fact that a variety of linguistic units larger

than a single word, but smaller than a full sentence, also facilitate the perspection of language.[1]

Generalizing to Reading

The theoretical explanation most often proposed for a verbal context effect stresses an interaction of contextual and visual information. The literature on word recognition in the presence of a verbal context readily suggests an interpretation of how perception of printed language occurs: Perception is assumed to be facilitated by a maximal use of the readily available contextual information to reduce the degree to which the perceiver must depend upon visual detail information afforded by the printed array.

In recent years, a number of theoretical approaches to the reading process have suggested that language constraints actually reduce the amount of visual information from the text which the reader must notice in order to make the requisite discriminations and identifications (Goodman, 1967; Haber, 1978; Smith, 1971). Morton (1964a) clearly enunciates this interactionistic position when he claims that "the presence of a context reduces the number of visual cues necessary for the correct identification of the word" (p. 176). When the reader is in the process of extracting information from a word, he already has the contextual information in mind. Therefore, efficiency is assumed to be gained by making use of the interword and intraword structural information inherent in the printed prose to circumvent some visual analysis. This explanation of the observed facilitation has been a consistent theme through the literature. The use

of contextual information to reduce the amount of visual information that must be extracted from the text is the typically hypothesized mode of processing in reading.

This position has been most exploited by those theorists who have adopted an analysis-by-synthesis approach (Haber, 1978; Hochberg, 1970; Levin & Kaplan, 1970; Wanat, 1971), or a guessing-game approach (Goodman, 1967) to reading. It is often suggested that the skilled reader is able to predict on the basis of language constraints many of the words to come next in a piece of connected discourse. Therefore, the reader only needs a minimal amount of graphic information, if any is needed at all, to verify predictions (Kolers, 1969; Smith, 1971). It seems axiomatic that the readers must extract some type of visual information from the stimulus display in order to read what is written in the text, even if it is only general word shape (Pillsbury, 1897), letter cluster information (Gibson, 1969), or first and last letter (Bouma, 1973; Brown, 1970; Eriksen & Eriksen, 1974). If the limited amount of visual information extracted from a text combines with the current contextual information, then there might be sufficient information to discriminate among word alternatives.

Many researchers have proposed mechanisms by which this process takes place (Brown, 1970; Haber, 1978; Levin & Kaplan, 1970; McConkie & Rayner, 1976b; Neisser, 1967). Brown (1970) suggested that the "pick up" of visual detail information from a word may occur in a fixed sequence or hierarchy. Such a "noticing order" deals with the grosser aspects first, like word length or overall pattern, and only later is internal word information

dealt with. The process of acquiring visual information could be discontinued once the word is identified. Thus, a greater efficiency of information extraction could be realized. Such a theory is consistent with many models of reading (e.g., Goodman, 1967; LaBerge & Samuels, 1974; Smith, 1971).

It is important to point out that the major source of evidence for this selectivity of visual detail perspective comes primarily from studies using impoverished stimulus information (e.g., Morton, 1964a; Tulving & Gold, 1963). These experiments involve stimuli which by their very nature afford the perception of only partial visual information. Therefore, a subject is required to make a judicious use of the limited information gained from the perception of stimuli in arriving at a response. When the structure of the text is highly redundant, then the subject will rely more heavily on that contextual information. The appropriateness of generalizing these results to reading is often questioned (Gibson & Levin, 1975; Gough, 1975; Cosky & Gough, Note 1).

While a great deal of work has been done investigating questions concerning the role of context in the perception of words and their component letters, there have been relatively few studies conducted with a task where people are engaged in normal reading.[2] Most research investigating perception in reading has taken one of two approaches. First, there are those studies (e.g., Tulving & Gold, 1963) where precise control of the stimulus presentation was achieved through the use of a tachistoscope, allowing a detailed analysis of the perceptual events. This

method has the undesirable characteristic of engaging the subject in a task quite different from normal reading. The typical design involves the perception of a single word under impoverished stimulus presentation conditions. Second, there are those studies in which the subject was engaged in a task more similar to normal, silent reading (e.g., oral reading tasks, letter and error detection tasks, or eye-voice span tasks). However, stimulus control has been all but impossible using these techniques. Thus, both methodologies have major problems for generalizability to conventional reading. One approach employs experimental paradigms that are unrepresentative of the reading situation, while the other employs paradigms that are typically quite weak because of the inability to make detailed stimulus manipulations.

Recently, there has been a flurry of research activity concerning the specific role of context in the reading process (Allington & Strange, 1977; Garrod & Sanford, 1977; Mitchell & Green, 1978; Perfetti & Roth, 1981; Stanovich, 1981; Stanovich & West, 1979; West & Stanovich, 1978; Frederiksen, Note 2; Gough, Alford, & Holley-Wilcox, Note 3; Juel, Note 4). These studies have demonstrated that the dominant role for a verbal context proposed by earlier researchers may have been overstated. Today, evidence is beginning to accumulate which supports a more attenuated role of context in reading.

Purpose of the Present Study

The current study was designed to investigate the ways in which a skilled reader uses prior contextual information to discriminate and recognize words in text. Specifically, the degree on constraint on a noun embedded in a short paragraph was manipulated by varying an immediately preceding adjective. The purpose was to determine whether or not subjects use contextual information to modify the information extraction process. Nouns that could be highly constrained by single preceding adjectives were identified. For example, the word botanical can make it highly probable that the next word in a paragraph concerning tourism in San Diego will be gardens. A number of paragraphs each containing one such target noun preceded immediately by a constraining adjective were written. A second version of each passage was also prepared in which the constraining adjective was replaced by another adjective. For example, the phrase botanical gardens was replaced by beautiful gardens. Thus, by the choice of an adjective, a noun in context could be highly constrained or left with considerably less constraint.

Secondly, by substituting various degraded spelling alternatives for the target nouns, this study investigated what spelling deviations could be made in the target nouns without such irregularities being noticed by the reader.[3] The purpose of this second manipulation was to assess the precise nature of the extraction process with regard to the noticing of specific graphemic information. The target nouns were altered in various ways in order to determine whether or not such distortions of conventional spelling

patterns would be disruptive to reading. Four experimental conditions for each of the two levels of constraint had spelling errors of differing severity.

Since the entire focus of this research was to study the perceptual process of reading in a representative situation (Brunswik, 1956), the task given to the subjects was simply to read the passages silently and be prepared to answer comprehension questions about them.

A study of eye movements during reading allows one to examine a number of fundamental perceptual issues of the reading process. The data patterns reflect the ongoing, immediate processing of the information in the text (Buswell, 1937; Dodge, 1907; Gibson & Levin, 1975; Huey, 1908/1968; Just & Carpenter, 1980; McConkie, Zola, Wolverton, & Burns, 1978; Rayner, 1978; Zola, Note 5). The dependent variables afforded by this technique permit a consideration of momentary cognitive processes ongoing throughout the reading of a text. Eye movement records indicate the locations in the text where the eyes were centered during fixations in reading. However, such knowledge alone does not indicate what region of the text was being seen. Vision researchers have studied the level of visual detail that can be perceived at different retinal locations and how this visual detail interacts with other factors such as the presence of other stimuli at specific locations in the visual field (e.g., Bouma, 1973). This type of research can indicate what visual information is potentially available from a printed passage when the eyes are centered at a specific location, but it can not indicate what region within this area is actually attended to

during a fixation in reading, or whether or not the attended region varies from fixation to fixation. In general, the eye movement paradigm research indicates that the region actually attended to during a fixation is influenced by the reading task itself (McConkie & Rayner, 1975). However, there is no evidence that indicates that the size or location of this region varies from fixation to fixation on the basis of contextual factors.

The current study was done under the assumption that if a reader only notices that part of the visual stimulus information necessary to discriminate among contextually permissible alternatives, then less graphic information need be extracted from words located in high-constraint regions of text; for example, maybe only word length coupled with initial and final letters would be sufficient for identification (Brown, 1970). If this assumption were correct, then subjects would not need to attend to other aspects of the visual detail. That is to say, unnecessary visual information would not be noticed or processed, and errors that did not violate the "needed" information would go unnoticed by the reader. In low-constraint regions of text, relatively more visual information would be "needed" for word identification. This position suggests that in some regions of text where lower constraint exists, more visual detail information must be noticed to complete the discrimination and identification process. Therefore, orthographic pattern distortions involving low-constraint textual regions should cause particular difficulty for the reading process.

The popular theoretical view of perception in reading described above would suggest that only severely degraded spellings would affect reading under high-constraint conditions where the target word could be identified on the basis of the prior context alone. However, less severe errors would cause difficulty in the low-constraint conditions. A single-letter error might have no effect in either condition, since the amount of visual detail being changed by such a pattern distortion might not involve information "needed" for word identification in context.

First, it was anticipated that the redundancy manipulation would be manifest in the eye movement records. Differential processing would be reflected in the time and distance measures of eye movement behaviors that occurred in and around the region of the manipulable adjective-noun phrase.

It was also anticipated that the various degraded spelling alternatives present in the texts would produce disruptions in the normal reading eye movement pattern. In essence, these alternatives were nonword letter strings. Therefore, it was reasonable to assume that as the reader's eyes got closer to the target phrase location, the reader would become aware of the spelling irregularities in the text. This awareness would be manifest in a change in the eye movement pattern. For example, there might be a longer fixation duration or a shorter saccadic length associated with the eye movement characteristics in and around the critical text region.

Specifically, differences were expected to occur in (a) the frequency of fixating the target nouns, (b) the amount of time needed to read a line

containing a target phrase, (c) the total time spent fixating on the critical noun location (CNL), (d) the durations of the initial fixations falling upon the CNL, (e) the length of saccades taking the eyes to the CNL, (f) the length of the saccades taking the eyes away from the CNL, and (g) the probability of regressing to the CNL. Therefore, the construction of appropriate dependent variables from the eye movement record were planned to serve as indices to examine these potential manifestations of processing differences and perturbations in the eye movement records.

Method

Subjects

Twenty undergraduate college students, who were considered to be skilled readers, were paid for their voluntary participation in this experiment. All were native speakers of English, had uncorrected vision, and were free of visual abnormalities. They were well experienced with the eye movement monitoring procedures employed. Each subject individually participated in three experimental sessions. The first two sessions lasted approximately 2 hours each, while the third session lasted only about 1 hour.

Upon completion of the entire experimental procedure, each subject was administered the Davis Reading Test (Davis & Davis, 1957). This standardized testing procedure was used to assess the overall reading ability of the subjects. The average level of comprehension score (M = 84.1, SD = 6.11) corresponded to the 86th percentile rank for adults, while

the average speed of comprehension score (M = 87.2, SD = 4.83) corresponded to the 93rd percentile rank. Self-reported SAT scores (mean verbal score = 601, SD = 59.12; mean quantitative score = 665, SD = 63.12) provided additional evidence that the group was quite adept at reading.

Materials

Experimental paragraphs. A number of approximately 60 word paragraphs were constructed, each consisting of a group of sentences that developed a single topic or idea. Each of these short prose segments was written to contain exactly 5 lines of text, with each line being between 69 and 73 character positions in length.

Embedded in each paragraph was a target adjective-noun phrase in which the degree of redundancy of a seven- or eight-letter noun was specified, to some extent, by the choice of the immediately preceding adjective. That is to say, the occurrence of the noun was highly probable following a certain adjective. The left column of Appendix A contains a sample of the kinds of phrases that were selected. The initial criteria for inclusion in this set were: (a) the noun had to be either seven or eight letters in length, (b) the adjective had to between six and nine letters in length, and (c) the adjective could not be a primary associate of noun (e.g., green grass was not an acceptable phrase).[4]

An alternate adjective was also identified for each adjective-noun phrase. Adjectives were sought that did not "suggest" the noun to follow with the same degree of certainty as the original word of the adjective-noun pair. Four further restrictions were placed on the selection of these

alternate words: (a) the alternate adjective had to be semantically compatible with the noun, (b) it had to be less constraining on the noun than the original adjective, (c) the number of letters in the constraining adjective and the alternate adjective had to be equivalent, and (d) the frequency of occurrence of the alternate had to be equal to or greater than that of the original adjective. In those cases where sufficient normative data were available (Kucera & Francis, 1967), this final criterion was met. The right column of Appendix A presents a sample of the alternative adjective-noun phrases.

Within each paragraph, therefore, both the original constraining adjective and the alternate adjective are semantically appropriate. Thus, the degree of redundancy of the target nouns appeared to be manipulable by the choice of the adjective that modified it. Two versions of each paragraph were prepared, one containing the constraining adjective and one containing the alternate word. The two versions of each paragraph differed by only one word. Appendix B contains a sample paragraph in which a highly constraining adjective followed by a target noun is presented.

The actual assessment of the predictability of the target nouns within the respective paragraphs was obtained in a procedure in which 150 subjects were asked to provide completions for over 200 paragraphic fragments. One hundred paragraphs were chosen from this set as the experimental texts for the current study. On the average, the target nouns for the selected texts were given as responses over 83% (M = 82.69, SD = 12.52) of the time in the more constraining verbal environment, and less than 8% (M = 7.95, SD =

9.50) in the less constraining instance. Without going into great detail concerning the paragraph norming and selection procedure, let me say that the high-redundancy category yielded substantially greater noun predictability than the low-redundancy category. An additional 32 paragraphs containing constraining adjectives and highly redundant nouns were selected for warm-up purposes.

Spelling errors. In order that the nature of the visual feature information of words that are noticed during reading might be assessed, specific misspellings of the target nouns were introduced into the experimental paragraphs. Four categories of degraded spelling were selected. The intent was to create a series of progressively grosser deviations from the conventionally spelled word. Figure 1 presents an exemplary composite of the five ways that the noun gardens was spelled in this experiment. These graduated alternatives were achieved by the substitution of letters according to the following scheme.

The minimal spelling degradation (referred to as condition DS1) was achieved by a single letter substitution. The fourth letter in each noun (e.g., the letter d in the word gardens) was changed to its most similar letter (see Figure 1). This type of spelling error often involved either the addition or deletion of one graphic feature of a letter (see Gibson, Osser, Schiff, & Smith, 1963). In a seven- or eight-letter word, the fourth letter is the word's most redundant letter (Bruner & O'Dowd, 1958; Garner, 1962; Miller & Friedman, 1957). The decision as to which letter was most visually similar to the original letter was based upon a

similarity matrix of all 26 lowercase letters obtained from an analysis of the same-different judgments for 24 subjects. This reaction-time experiment will not be reported here, but it is important to note that the graphic display and alphabetic character set used to present the letters for judgment was the same unit used to present the text displays of the current study.

In the next, more gross type of spelling degradation (referred to as condition DS2), the fourth letter of the original noun was changed to its most dissimilar letter within the same letter set (see Figure 1). The notion of letter set refers to the division of the alphabet into ascenders, descenders, and all other letters. The psychological importance of such a discriminative division of the alphabetic characters is evident in the clustering tendencies of letters that are reported in studies involving the analyses of alphabetic similarity matrices (e.g., Bouma, 1971; Dunn-Rankin, 1968; Geyer, 1977).

The third type of spelling degradation (referred to as condition DS3) was achieved by substituting alternative letters for the fourth and fifth letters in each noun. This manipulation had the effect of changing the word's external shape or envelope. The fourth letter was again changed to its most similar letter, while the fifth letter was changed to a randomly chosen letter from another set (see Figure 1).

The grossest degradation of the original noun (referred to as condition DS4) was constructed by substituting for the fourth letter its most dissimilar letter within the set, and by changing the first and last

letters to randomly selected letters from sets other than the original letters (see Figure 1). This manipulation was motivated by the well-documented fact that the first and last letters of a word have a greater cognitive saliency than internal letters (e.g., Broerse & Zwaan, 1966; Bruner & O'Dowd, 1958; Eriksen & Eriksen, 1974; Gibson & Levin, 1975; Huey, 1908/1968; Woodworth, 1938).

Comprehension assessment procedure. In order to ensure that the subjects read the paragraphs and understood their basic content, comprehension questions were constructed and administered. The questions always dealt with information stated in the paragraphs or with information which could be directly inferred from the paragraphs. However, the questions never involved the target noun or its respective preceding adjective. This procedure was used to keep the subjects from focusing on the words that were misspelled. Thus, the comprehension test also served to define the experimental task as one of reading for general passage understanding, and not one of searching for and detecting errors.

Equipment

Monitoring system. A computer-based laboratory system was used for displaying the texts to be read and for monitoring and recording the eye movement patterns of the subjects engaged in reading. (For a more detailed description, see McConkie, et al., 1978.) Basically, this laboratory facility is centered around a Digital Equipment Corporation (DEC) PDP 11/40 computer with a laboratory peripheral system and a DEC VT-11 graphics display system. The graphic display unit consists of a cathode-ray tube

(CRT) driven by its own special processor. It is the automatically refreshing type that produces a bright, continuous image. The tube's P-31 phosphor is of short persistence, green in color, and decays to one percent of the original intensity within 500 microseconds.

A modified Biometrics Model SG eye movement monitoring system of the limbus reflection type (Young & Sheena, 1975) was used in this experiment to track the movements of the subjects' right eye.

Software characteristics. Two general purpose computer programs, written in assembly language, were used for the collection and reduction of the eye movement data.

The main data collection program served two functions: (a) the calibration of the monitoring equipment and (b) the recording of the actual eye position information. In the present study, calibration of the eye movement monitoring equipment was accomplished by having a single boxed dot, whose extent equalled one character position, appear in isolation at five equally spaced positions on the horizontal midline of the display scope, and by having the subject directly fixate the dot and press a button. At the moment the subject's response was made, the computer sampled the eye position signal. This five point calibration pattern was presented twice in succession. If the individual samples obtained during the second presentation were within a threshold equivalent to one-half of a character position, then the average of the two samples was stored as a precise location value in a calibration matrix. If the threshold criterion was not met, then sampling of the deviant location was repeated until the

criterion was achieved. Subjects were required to complete the calibration task prior to and immediately following the reading of each passage. These before and after calibration matrices were used in the data reduction process to translate from eye monitoring equipment voltage levels to display scope locations. Such location indices corresponded to textual letter positions. In other words, a direct mapping of the position of the eyes to the stimulus was made.

Eye position was sampled at a rate of 1000 times per second. The subject's button press brought the next line of text to the display scope within a few milliseconds. The texts were displayed one line at a time. Thus, reading proceeded quite easily within the constraint that the subject could not visually jump from one line of text to another and then return.

The data reduction program served two functions: (a) the identification of saccades and fixations evident in the eye position signal, and (b) the translation of the location of fixation data values into relative character position information. First, the program located the beginnings and ends of saccades using an algorithm based upon the velocity and trends of consecutive data samples. Disturbances in the eye movement pattern caused by eye blinks were designated as such, and were visually examined for classification purposes. Then the data were summarized in a reduced form preserving only needed information. The final phase of the reduction program provided a linear interpolation of the fixation location value in terms of character positions of scope location. This translation procedure was based upon the passage specific calibration matrices recorded prior to and after the reading of each text.

Design

The design employed in this experiment was a 2 x 5 within-subject factorial; specifically, there were two levels of noun redundancy afforded by the nature of the preceding adjectives, and five levels of spelling. For ease of discussion the levels of the redundancy variable are referred to as either high-redundancy or low-redundancy. And the levels of the spelling degradation variable are referred to as Levels 1 through 4, with the control conditions corresponding to those paragraphs containing the conventional spelling patterns of the nouns.

The complete set of experimental paragraphs containing the highly constraining adjectives and corresponding redundant nouns was completely randomized and subsequently divided into 10 groups of 10 paragraphs each. Corresponding versions of each paragraph were generated for the other nine experimental conditions. These composite groups of paragraphs were then rearranged according to appropriate counterbalancing procedures to systematically vary the grammatical function of the noun, the location of the noun within the line, and the location of the critical line within the paragraph itself. This scheme yielded a series of ten sets of ten paragraphs with each condition appearing only once in a set. Each set was then randomly ordered, and divided in half. The resulting subsets of five paragraphs were called passages. In the beginning of each passage, an additional paragraph that contained no spelling errors was inserted. Thus, each of the resulting twenty experimental passages consisted of six short paragraphs each.

As a further safeguard against a practice effect confounding the results, the presentation order of the texts was rotated among passages for the first group of 10 subjects, with each subject beginning with a different passage following the common warm-up passage. This sequential order was then reversed for a second group of 10 subjects.

Procedure

Each subject was seated in an adjustable and comfortable experimental chair and was physically positioned in a manner conducive to head stability. A bite bar was also prepared and used to limit head movement. The display scope was positioned 48 centimeters away from the subject's eyes. Since a dim, direct current lighting level was used in the experimental room, a period of between 10 and 20 minutes was taken to allow the subject to reach complete dark adaptation.

After a brief, initial calibration of the eye position monitoring equipment, the experimental procedure was explained. The subject was told that the text materials were a series of five-line paragraphs, each dealing with a different topic, and that there were intentional errors in the texts. It was further explained that the errors were unimportant, had no bearing on the task at hand, and could be ignored. This procedure was adopted after pilot sessions indicated that if subjects were not told that errors would be in the text, they quickly adopted a strategy of looking for errors and spontaneously commenting that "some of the words are spelled wrong." The initial group of 12 warm-up paragraphs was presented to acquaint the subject with the task of reading text with minor spelling

errors, not an uncommon everyday experience. A comprehension test consisting of questions based on the information contained in the practice paragraphs was also administered to familiarize subjects with the type of knowledge that they would be expected to gain from the reading.

After reading the initial warm-up paragraphs, the subjects were told that there was a bonus consideration for correctly answering the questions on the comprehension test. Each test set consisted of five questions related to the paragraphs. Since there were six paragraphs in each passage, some of the paragraphs would not have any questions associated with them. However, since the subjects did not know which paragraphs were to be tested, it was suggested that they read each paragraph for a general understanding of its topic. The subjects were also informed that the questions were based upon the information stated in the paragraphs or on information that could be directly inferred from the paragraphs. For each correct answer, the subjects would receive a 5¢ bonus. The results of the comprehension test and amount of bonus monies earned were always reported to each subject immediately after the written questions were completed. The bonus was awarded in addition to a standard experimental fee.

Then, the experimental paragraphs were presented in groups of six, each paragraph followed by a line instructing the subject to go on to the next paragraph. After each group of six paragraphs, the subject was administered the set of five comprehension questions associated with the paragraphs just read. Each subject read ten paragraphs under each condition. Every subject received a different order of presentation

because of the within-set randomization procedure. And every pair of two consecutive passages contained one paragraph under each of the ten experimental conditions. Two experimental sessions were needed to complete the reading of all 132 paragraphs. A final session was used for debriefing and for the administration of the Davis Reading Test.

After the final experimental passage and corresponding comprehension test had been completed, the subjects were given excerpts of the last 12 paragraphs that they had just finished reading. These excerpts consisted of the exact wording of the paragraphs up to, but not including, the target letter string. The subjects were unaware that this further procedure was to be required of them. They were told that the excerpts were from the last few paragraphs read, and were asked to add, as best as they remembered, the next two or three words that were in the original text. Subjects were encouraged to write down the spelling of a word as it appeared in the paragraph, or at least make note of the fact that one or more words was misspelled in the original passage. A short debriefing session followed.

Results

Dependent Variables

The data that are presented involve four aspects of the eye movement behavior of the subjects.[5] They are: (a) location of fixations (i.e., where in the text readers centered their eyes for pauses), (b) total line reading time (i.e., the number of milliseconds that the text line

containing the critical phrase was displayed), (c) duration of fixations (i.e., the length of time in milliseconds of the pauses at each location), and (d) distance of saccade (i.e., the length and direction of an eye movement in terms of the number of letter positions traversed).

Data Elimination

A portion of the data had to be eliminated because of disturbances in the eye movement records caused by eye blinks, which interfered with the continuous sampling of eye position information, and because of head movement, which made the accuracy of the eye position information ambiguous and rendered translation questionable. Table 1 presents a breakdown of the instances of data elimination with respect to fixations centered upon the critical noun location (CNL) for each of the experimental conditions of the design. It can be seen that an approximately equivalent amount of data was discarded from each of the various experimental treatments.

Statistical Model

In order to determine whether or not the subjects' eye movement patterns were significantly affected by the experimental factors, and to search the data patterns for answers to a number of experimental questions, analyses of variance were carried out for the dependent variables enumerated below. Throughout these analyses, the redundancy variable was treated as a random factor (Clark, 1973), and the degraded spelling factor was treated as a fixed factor. Thus, the appropriate ANOVA assuming a mixed effects model for the experimental variables was adopted as the

principle model for hypothesis testing. Such a statistical conceptualization allows for the legitimate generalization of the findings to the more inclusive population of linguistic segments involving interword redundancy.

When the analysis procedures revealed significant main effects for the degraded spelling factor, a set of four orthogonal comparisons was calculated to test for significant differences between control and experimental group means. Occasionally, the main results suggested interesting additional, a posteriori theoretical questions. Therefore, post hoc comparisons (Kirk, 1968) were made.

Assumptions of homogeneity of variance among groups for each of the dependent variables were checked using the F-max procedure (Kirk, 1968). When violations of relative equality of variance among treatment groups existed, a logarithmic transformation was performed on the median data before ANOVA procedures were performed. This transformation was effective in normalizing distributions with positive skewness. On three occasions dependent variables involving fixation duration did violate assumptions of homogeneity of variance. In each case the distribution of durations was positively skewed, as is common with reaction-time measures. However, in each case the ANOVA procedure using the untransformed data revealed significant differences that corresponded to those found with the ANOVA procedure using the normalized data values.

Medians for a Three-Letter-Position Region

Both inherent monitoring equipment limitations and minor subject head movement introduced inaccuracies into the calculation of exact eye position information. Therefore, the precision of determining the exact letter being fixated is restricted to a range of plus or minus one letter position. In other words, the ability to calculate from the eye movement record the exact letter upon which a fixation is centered often involves some error. And, it is also true that the distribution of fixation durations is markedly skewed. Several long fixation durations "pulled" the distributions in the positive direction, greatly influencing the mean as the measure of central tendency. For these two reasons, the construction of most of the dependent variables for each subject involved the selection of a median value obtained from a three-letter-position region. For example, if the letter position of interest was the fourth character position of a word, then the fixation durations associated with the translated third, fourth, and fifth letter positions were used as the data base from which the individual subject's median response was calculated. This statistical "filtering" technique yields relatively stable estimates of the dependent variables under consideration.

Location of Fixation Characteristics

Probability of fixation. Did subjects fixate the target noun when it was highly predictable? In the high-redundancy condition, the usefulness of the semantic information "contained" in the target noun is minimal. Therefore, it was not known a priori whether or not such an uninformative

word would even be fixated. Since the preceding context almost completely specified the word, the semantic content of the word is not really needed to achieve an understanding of the passage. Table 2 shows the percentage of times that the CNL (critical noun location) was fixated in the 10 experimental conditions. It is quite clear that subjects paused on the CNL in both high- and low-redundancy conditions. Subjects caused their eyes to be centered on the CNL over 95% of the time in all conditions.

In order to take full advantage of the semantic interword redundancy afforded by the text, it is necessary to identify the adjective preceding the target noun. Therefore, the percentages of times that the critical adjective location (CAL) was fixated are also given in Table 2. It likewise can be seen that subjects fixated the adjective a large proportion of the time under both the high- and low-redundancy conditions.

Distribution of fixations. The percentage of time that a word is fixated provides a fairly gross indication of information extraction in reading. To gain a better understanding of the experimental effects, a relative character position analysis of those locations of fixation was carried out. Relative character refers to the location of the specific letters of the target phrases in relation to a standard location. Throughout this discussion, the space between the the two critical words in each phrase is referred to as relative character position 0. Figure 2 presents two frequency distributions of fixation location plotted over each relative character position. The distributions represent the two control conditions of this study, namely, the high- and low-redundancy conditions

that contained no spelling degradation. A sample line of text is printed on the horizontal axis of Figure 2 to emphasize the correspondence of the relative character positions and the target phrase location. The frequency values at each location represent a mean of subject medians for a three-character region. The target nouns occupied locations of 1 to 7 or 1 to 8 to the right of the 0 location, while the target and alternative adjectives occupied the locations 1 to 7, 1 to 8, or 1 to 9 to the left of the 0 location. The distributions of location of fixations presented in Figure 2 are identical ($\chi^2 = .19$, $p > .75$). There is no evidence in the eye movement records to show that the highly redundant noun was bypassed or skipped. Where readers look was not being affected by the interword redundancy afforded by the language structure of the adjective-noun phrases.

Temporal Characteristics of Eye Fixations

Is there any evidence in the eye movement records of differences or perturbations in the temporal characteristics of subjects' eye movement behavior that were associated with the processing of the target phrase? In order to answer this question, several different ways of assessing the amount of time required to process the critical words were undertaken. However, all these dependent variables showed the same basic trends.

Line reading time. According to the experimental procedure described above, the presentation of the text was under the complete control of the subject and involved single line displays. A subject's button push was used to request each new line of text. Therefore, an indication of the

time taken to read a line of text was constructed by calculating the number of milliseconds between button pushes. This dependent variable is referred to as line reading time (LRT). Figure 3 presents a graphic representation of the relationship between the estimated reading times for lines that contained the target phrases and the experimental manipulations. This data pattern is consistent throughout all of the various analyses of the temporal characteristics of eye movement behavior.

ANOVA procedures revealed a main effect for the degraded spelling factor, $F(4,4) = 43.61$, $p < .002$. In the first column of Table 3, the average line reading times in milliseconds for the control and experimental conditions are presented along with the overall standard deviation range limits.

Aggregated time fixated on CNL. Next, a dependent variable that included only those fixation durations resulting from foveal fixations of the CNL was constructed. The total amount of time spent fixating the critical noun location (CNL) consisted of only those fixation durations resulting from pauses where the eyes were centered on one of the letter positions of the CNL.

It should be pointed out that this dependent variable includes an aggregation of time from all sources. That is, it includes the time from initial fixations, regressive fixations, and multiple fixations that were centered on the target region. Again, the general trend in the data pattern provides evidence that additional amounts of time were being spent fixating the target locations as a function of spelling pattern. Even in

those conditions that contained no spelling degradations, a 23 milliseconds difference between the high- and low-redundancy conditions was observed (see column 2 of Table 3).

Analysis of the initial fixations on the adjective-noun phrases. Another way to examine the influence of the experimental manipulations on the temporal characteristics of the eye movement patterns is to consider individual fixation durations in the region of the critical adjective-noun phrases. Such an analysis is based upon a fundamental immediacy-of-processing assumption. That is, the information which is noticed during each fixation determines the course and characteristics of the eye movement pattern in the region of that fixation. Furthermore, the duration of a foveal fixation of a specific region of text reflects the information extraction process. Therefore, a subject's initial fixation on a word is of great interest. This analysis is concerned with only those fixations that were located at one of the letter positions of the target phrases, and with only the initial fixation of the critical words or deviant letter strings. The construction of the dependent variables involved the duration of only the first fixations that fell upon the CAL (critical adjective location) and the first fixations that fell upon the CNL (critical noun location). For each subject, a median value was selected from all the initial fixations located on either of the critical words. Each subject contributed one median fixation duration value for each of the ten conditions. This value was derived for each subject for each condition based on a maximum of 10 observations. Due to data elimination

considerations discussed above, the number of data values upon which each median value was based was more typically six or seven durations. It is important to point out that the probability-of-fixating analysis discussed above clearly showed that all of the critical words were directly fixated with high frequency. Therefore, fairly stable estimates of the time a subject spent in initial foveal fixation of either word in the target phrase were available. These summary statistics were used as indices to examine the temporal effects on the eye movement patterns. Columns 3 and 5 of Table 3 present the means of medians for each of the experiment's conditions for the CAL and the CNL regions, respectively.

The analysis of the median durations on the CAL revealed no difference across all experimental conditions. In other words, the initial fixations on the adjective location exhibited no differences or perturbations in fixation durations in the region just prior to the CNL.

ANOVA procedures for median fixation durations on the CNL revealed significant main effects for the redundancy factor, $F(1,190) = 5.57$, $p < .02$, and for the degraded spelling factor, $F(4,4) = 17.22$, $p < .01$. However, these two factors did not interact, $F(4,190) = .67$, $p > .61$. Comparison procedures among the condition means revealed that neither of the two single-letter substitutions caused significant inflations in the foveal fixation durations of the CNL when compared to the control condition. However, the two, more grossly degraded spelling conditions did differ from the control condition. This analysis suggests that the deviations in orthographic structure cause perturbations in the eye

movement patterns in the form of inflated fixation durations when the deviation involved more than a single erroneous letter substitution, and when the eyes were centered on one of the letter positions of the deviant word.

Ambiguity of word-fixation analysis. A conceptual difficulty with an analysis procedure that assigns all the fixation time to a word unit concerns the assumption that the word information being noticed and used for extraction is the word upon which the fixation falls. For example, those fixations located on the final letters of the CNL present ambiguity with respect to which word or words are being noticed. Is the reader extracting information from the word just to the left of the fixation location? Is the reader encountering the information about the word just to the right of the fixation location? Is extraction from both words being simultaneously or sequentially performed? The underlying issue here involves the fact of an asymmetry of the perceptual span in reading. McConkie and Rayner (McConkie, 1979; McConkie & Rayner, 1975; 1976a; Rayner & McConkie, 1976) present some data on this matter and suggest that information to the left of the fixation point is seldom used in reading. The analyses of initial fixations discussed above did include those fixations that fell upon the last one or two letter positions of the CNL to contribute data to dependent variables. This fact creates some ambiguity with respect to the validity of this dependent measure. Consider the case were the CNL contained a minimal spelling degradation. In the ambiguous cases, the fixation location was beyond the erroneous letter.[6] Therefore,

was the subject really extracting the critical letter information? A similar contamination of the CAL analysis also exists.

Thus, an analysis procedure which assigned processing time to total words based upon individual fixations that fell anywhere within the bounds of the word may in fact be specious. Therefore, an alternative analysis procedure was adopted to eliminate the questionable fixation data.

Analysis of the initial fixations on the fourth letter of the critical words of the adjective-noun phrases. In an attempt to remedy the ambiguity present in the previously discussed analysis procedure involving initial fixations of the critical word locations, similar analyses were conducted using only those fixations that fell on the third, fourth, and fifth relative character positions. From an inspection of the frequency distributions of location of fixation (see Figure 2), it was discovered that approximately 60% of the data were included in this analysis procedure. In other words, the typical pattern of inspection involved fixations located at either the third, fourth, or fifth letter position of the target words. From what is known about functional stimulus in reading (McConkie & Zola, 1981), these fixations most probably involved a noticing of the critical letter string. Therefore, the problems previously discussed concerning initial fixation duration analysis were eliminated.

The analysis performed upon this data set concerns those fixations that fell upon the middle area of the CNL. This statistic proved to be a very sensitive index of the effect of the experimental manipulations. Even the minimal spelling degradation produced an inflated fixation duration,

suggesting that small deviations in spelling pattern are noticed when the erroneous information is foveally fixated (see Figure 4).

ANOVA procedures using the log-transformed initial fixation duration data for the CAL again revealed no differences in inspection time (see columns 3 and 7 of Table 3). This analysis for initial fixations on the CNL revealed main effects for the redundancy factor, $F(1,190) = 5.65$, $p < .02$, and the degraded spelling factor, $F(4,4) = 96.67$, $p < .0003$, whereas the interaction of the two factors was not significant, $F(4,190) = .10$, $p > .98$. Orthogonal comparisons demonstrated that each of the experimental conditions significantly differed from the control group at a probability level of .01 (see column 9 of Table 3). These results have profound implications for conceptualizations of the reading process. It appears to be the case that the foveal fixation of a word does involve the noticing of specific letter information from those letters that are the focus of attention of the saccadic system. Centering a word upon the fovea does apparently ensure the "pickup" . . visual detail information even in highly redundant text regions. Such a position is compatible with several theories of word perception (Eriksen & Shultz, 1978; Gibson, 1971).

Analysis of Saccadic Length

Is there any evidence in the eye movement records for differences or perturbations in the distance the eyes moved in and around the region of the CNL? In other words, did the experimental manipulations affect the lengths of specific saccades?

The distance that the eyes traversed in moving to and going from individual fixations on the critical noun location provides a way of examining the influence of the experimental manipulations on another major characteristic of eye movement patterns, namely, saccadic distance. The following analyses parallel the individual fixation duration analyses discussed above. That is, the first analysis of saccadic length involves a consideration of individual forward movements of the eyes that resulted in an initial foveal fixation of the CNL. The second pair of analyses consider the saccadic lengths associated with foveal fixations of the fourth letter position region on the CNL. In all cases, the distance of the movements is expressed in terms of the number of character positions traversed.

Analysis of saccadic lengths associated with the initial fixation of the CNL. The analysis of the median saccadic lengths for forward movements resulting in fixations on the CNL revealed a significant main effect for the degraded spelling factor, $F(4,4) = 15.69$, $p < .01$. The difference among condition means was attributable to the DS4 condition manifesting a significant foreshortening of forward movements when the word to which the eyes were being sent was grossly misspelled.

An analysis of the saccadic lengths for forward movements following a foveal fixation on the CNL showed differences in saccadic size as a function of the level of degraded spelling factor, $F(4,4) = 145.89$, $p < .0001$. However, neither the redundancy factor, $F(1,190) = 1.84$, $p > .17$, nor the interaction of the two factors, $F(4,190) = .05$, $p > .99$, revealed any differences (see column 6 of Table 3).

Analysis of saccadic lengths associated with the initial fixation of the fourth letter position of the CNL. The saccadic length analyses of forward movements to the fourth letter position of the CNL are similar in pattern and significance to the previous analysis of saccadic length for movements bringing the eyes to the CNL (see columns 4 and 8 of Table 3). Neither the redundancy factor, $F(1,190) = 1.23$, $p > .26$, nor the interaction of the two factors, $F(4,190) = 1.07$, $p > .37$, revealed effects. However, the degraded spelling factor did achieve significance, $F(4,4) = 9.42$, $p < .03$. The effect can be attributed completely to the most deviant spelling condition, $F(1,4) = 34.23$, $p < .01$.

The analysis of the length of saccades leaving this circumscribed region of text revealed only a significant main effect for the degraded spelling factor, $F(4,4) = 11.56$, $p < .02$. Neither the main effect for the redundancy factor, $F(1,190) = 1.52$, $p > .21$, nor the interaction, $F(4,190) = .62$, $p > .65$, achieved significance. The contrasts among group means for the degraded spelling factor revealed significant effects for the DS4 condition, $F(1,4) = 35.94$, $p < .01$, and the DS3 condition, $F(1,4) = 8.75$, $p < .05$ (see column 10 of Table 3).

Analysis of the probability of regressing to the CNL. An analysis of the directionality of the eye movements in the region of the target nouns revealed that the proportion of fixations falling on the CNL that were immediately preceded by a regression increased as a function of experimental condition. In the high-redundancy control condition, the proportion was 4%, whereas, in the DS1 condition the proportion is 16% (see

Figure 5). Statistical analyses were carried out using the arcsine transformation (Winer, 1971) of probability of regression as the dependent variable. Frequency of regression was significantly greater for the minimal error conditions than it was for the control conditions, $F(3,3) = 101$, $p < .002$. This analysis adds further support to the claim that even the minimal spelling error had an effect on the eye movement behavior of subjects in this study.

Summary. The interword structure of the target phrases had no effect on where the subjects centered their eyes (i.e., the location of fixation), but did have an effect on how long individual pauses (i.e., fixation durations) were at those specific locations corresponding to fixation on the target nouns. Overall, the trends in each of the dependent variables concerning the CNL are remarkably similar. In no analysis did the two experimental factors interact. In all analyses, the mean fixation time for the low-redundancy condition was always greater than the mean time for the corresponding high-redundancy condition. In all analyses, the levels of degraded spelling manifested a commensurate increase in fixation frequency and duration. The analysis of saccadic lengths showed perturbations of eye movement pattern only with the grosser spelling degradations, and not with the redundancy factor. However, an analysis of regressive movements did added further support to the claim that minimal orthographic deviance was noticed by the readers.

Discussion

The data patterns revealed by this study are informative with respect to several of the fundamental perceptual issues of reading. The section that follows presents a discussion of five topics to which the current data speak. First and foremost, the data provide evidence that interword redundancy facilitates the extraction of information from text. In other words, the data show that the presence of a highly constraining verbal context does make a difference in the processing time related to the perception of an individual word, albeit an apparently small real-time savings. The data further suggest that this observed perceptual facilitation does not result from circumventing the extraction of certain aspects of the visual detail information that is afforded by the printed text. In fact, readers do notice a great deal of visual detail information during a fixation within the region of text falling upon the fovea. Thirdly, the study also addresses issues related to the control of eye movements in reading. The notion that readers only fixate informationally rich areas of text (Hochberg, 1970) is not supported by the data, whereas, information about typical fixation location within words is revealed. Fourthly, the data support the claim that the duration of a fixation in reading reflects the characteristics of the stimuli being perceived on said fixation. The degree of constraint on the nouns influenced the duration of fixations located on those nouns, and the erroneous information present in the degraded spelling conditions also influenced the durations of the direct fixations of the nouns. Finally, some tangential comments are made

about the unit or units of perception in reading. The data patterns from the degraded spelling conditions indicate that skilled readers are noticing specific letter information. This finding suggests that letter information is cognitively prominent in silent, skilled reading.

A Verbal Context Facilitates Extraction of Information

In all the analyses involving the duration of fixations that fell upon the CNL, the levels of the redundancy factor manifested temporal differences attesting to the robust nature of the effect across a variety of dependent variables. The results of this study clearly show that differences in foveal fixation duration of the target nouns exist between the high- and low-redundancy control conditions. If a word is highly constrained, less time is spent when the word receives a direct foveal fixation (i.e., the fixation's location in the text is centered on one of the letters of the word). However, the significant 16 msec difference revealed in the analysis of those fixations that were located within the middle region of the CNL is not of the magnitude found in earlier perception research. For example, Tulving and Gold (1963) demonstrated that a 27 msec difference existed in the visual duration thresholds for words when a word to be identified was presented under conditions of no preceding context and under conditions of full-sentence context. This more pronounced effect, present in many word recognition studies, may be attributable to a repeated presentations confounding or to a guessing strategy adopted on the part of the subjects. Neither of these two nuisance variables are involved in the normal reading task.

Potential Explanations of Contextual Facilitation

The effect of facilitated extraction seeks an explanation as either a perceptual phenomenon or a memorial phenomenon (i.e., the effects may come from where one looks and/or how one recognizes and remembers what was seen). Three alternative explanatory hypotheses for this effect are considered.

Selectivity within the text region being fixated. It has often been suggested that readers can choose to attend to only certain aspects of the visual detail information of printed text. Consider the notion of a hierarchical extraction of visual information. Such a perspective suggests that the graphic information in a visual array of language stimuli is noticed in a precise order. Once sufficient information has been extracted to provide the basis for discrimination, the extraction process ceases. This perspective further suggests that the reader uses the contextual information and an ordered series of extraction principles to achieve recognition. Brown (1970) precisely specified an algorithm that would meet these criteria. First, the initial and final letters of a word are noticed, if a decision can be made from this minimal inspection, then no further visual detail is encountered. If recognition is not achieved, then the reader proceeds on a type of internal scan encompassing more and more visual detail information until identification is achieved. The data patterns from the current study suggest that such a strategy is not the conventional mode of processing in reading. Such notions of a hierarchical word identification process (e.g., Johnston, 1978) are often presented in

opposition to the wholistic perspective of word perception without offering any explanation of the enhanced perception of words in context other than to suggest that important letter analysis procedures can be "bypassed" under certain circumstances. The research cited to support this notion of decreased sensitivity to visual detail in the presence of a verbal context involves studies where the stimulus is already impoverished by either degradation, error, or subthreshold presentation. Therefore, the basic receptive process might be altered and thereby the nature of what will be an adequate visual stimulus might change. Tachistoscopic word recognition research has led theorists to speculate that the identification of partial feature and letter information in combination with subject expectations based upon language regularities can explain the process of word identification. However, in normal reading, the stimulus is rich in veridical information. The presentation of such information is controlled by the reader and not the experimenter. Therefore, the extraction and identification process may be quite different in single-word recognition tasks as opposed to conventional reading.

The current study was carefully designed to reveal such informational selectivity, but failed to find any evidence for its occurrence. The evidence from this study goes against the conventional "top-down" interactionist interpretation of the data patterns from word recognition paradigms. A question of particular interest thus became whether or not subjects detected the minimal error embedded in the CNL in the high-redundancy condition. The results of the current study revealed that

single-letter deviations in highly redundant locations in text were noticed by, or affected the processing of, subjects, at least by some of the subjects some of the time.[7] Even in the minimal error condition where a single internal letter of a noun was replaced by a similar, albeit incorrect letter, significant effects on fixation duration and on the probability of regression were revealed. This finding suggests that the information was not ignored or skipped, but was actively extracted from the visual array. Readers are sensitive to the visual feature information that is on the fovea during a fixation in reading.

Semantic priming. If the suggestion of reduced dependence on visual detail is incorrect as an explanation for enhanced perceptibility, then the literature on semantic memory provides a strong alternative. Identification cuing or semantic priming studies have clearly shown that specific single-word verbal contexts which are related in some manner to the stimulus word can produce a facilitation of perception greater than the enhanced extraction observed in the current experiment.

There is one very disturbing fact about the "priming phenomenon" that calls into question its use as an explanation for the facilitation observed in this study. Researchers have demonstrated that the interstimulus interval needed to achieve significant effects of priming is approximately 400-500 milliseconds (Neely, 1976, 1977; Posner & Snyder, 1975). Such an interval would not typically have been available in this study. The median fixation duration of subjects in the current study was 220 milliseconds. Recent evidence suggests that a word is noticed or encountered during only

one forward fixation (McConkie, Note 6). Thus, if a specific constraining adjective was "seen" once, even if there was an immediate word identification at the beginning of that fixation, there was rarely a fixation duration observed in this study of the magnitude necessary for priming or cuing to occur. Some researchers have suggested the possibility of some type of automatic priming (Marcel & Patterson, 1978) from peripheral vision that suggests that a specific word is actually noticed more than once. However, recent evidence from Rayner (1979b) suggests that parafoveal information is not effective as a priming stimulus. This concern presents enormous compatibility problems with respect to what is known about the temporal characteristics of the semantic priming process and the extraction of visual information from the paragraphs of this study as suggested by the eye movement data.

When one considers reading in a broader sense, there are two other findings which also question the influence of priming on the reading task. First, the highly transitory nature of priming (Cramer, 1969) suggests that words noticed early in the reading of a text would have no priming influence on words noticed later. The supposed activation of related semantic nodes is quite short-lived. In the very best case, the influence of priming would not last more than 30 sec. Secondly, the contiguous nature of a typical priming sequence suggests that in order for a priming effect to be occurring in reading, the related words must be very close together. Therefore, accepting a priming position toward contextual facilitation means that only relatively contiguous words or phrases can

influence processing, and that titles and other such important headings noticed early in the reading of a book or article can not effect the efficiency of information extraction during later reading. However, it has been shown that knowing the semantic context established by a piece of connected prose does influence the processing of subsequent sentences (Dooling, 1972).

Higher-order information integration. A third way to conceptualize the interword facilitation exhibited in this study is based upon the idea that contextual and featural information combine to create a new stimulus dimension, a higher-order structuring of information that permits greater efficiency of extraction. All of the visual detail that is available from the foveal fixation is noticed vis-a-vis the contextual information that is currently in mind at that moment.[8] Linguistic redundancy can facilitate information "pick up" if the two sources of information can combine to produce a new dimension that is better for information processing than either dimension alone.

There is much evidence to suggest that higher order units are easier to process (Cattell, 1885/1947; Felfoldy, 1974; Garner, 1962; Gibson, Tenney, & Sharabany, 1971; J. Gibson & E. Gibson, 1955; Palmer, 1975a). For example, it is known that words are easier to recognize than pseudowords, and pronounceable pseudowords are easier to recognize than unpronounceable letter strings (Gibson, Pick, Osser, & Hammond, 1962). This fact means that information can be integrated across separable dimensions of the stimulus information. When the dimensions can be used

redundantly, there is facilitation in information extraction. Furthermore, the more familiar the relational structure is to the perceiver, the greater the facilitation (Palmer, 1975a, 1975b). The notion of some type of higher order integration of information has great appeal in light of the data patterns manifest in the current study. By eliminating the decreased sensitivity argument and the semantic priming perspective as explanations of processing facilitation, one is left to seek an alternative explanation in terms of the unit of perceptual processing. The issue of the nature of the integration of information in creating this new, "high order" dimension is a fascinating one. Does such a combination involve a selective and active perceptual process (Gibson, 1972), or does it involve a mandatory and automatic perceptual process (Shiffrin & Schneider, 1977)? This topic awaits future research.

Verbal Context and Eye Guidance

It is often suggested (e.g., Hochberg, 1970; Haber, 1978) that people only fixate informationally rich areas of a text. The linguistic hypothesis of eye movements in reading (O'Regan, 1979a, 1979b) suggests that the eyes skip over regions of text about which good predictions can be made and go to regions in the periphery about which there are inadequate predictions. In the current study, the highly redundant target nouns on the average received just as many fixations as did the less constrained nouns. There also appears to be a convenient or preferred viewing location within a word for the locus of fixation (Rayner, 1979a). In the current study there was a preponderance of fixations toward the middle of both the

adjectives and the nouns. Thus, these data patterns call into question the position that fixation location is contingent upon the locus of information.

It is a well-known fact that the eyes are guided in some nonrandom manner (Rayner & McConkie, 1976). In the current study, differences in saccadic length observed for the most deviant spelling degradation conditions provide evidence that some information about a subsequent word is noticed on the preceding fixation. The information that is noticed does not affect the fixation duration but only the length of the following saccade. This data pattern suggests that at least visual configuration information is noticed: for example, the initial two letters of a subsequently fixated word. The current study was not designed for experimental analysis of eye guidance issues per se; therefore, little can be said beyond the speculative. But it does seem clear that noticing an extremely deviant letter string not only affects the saccade that brings the eyes to that word but also affects the length of the saccade that leaves the deviant word. One suggested explanation is that the very deviant letter string requires a great deal of attention to disambiguate the spelling pattern in order to arrive at a reading. This demand in some way restricts the noticing of peripheral information.

Recent studies by Hogaboam (Note 7) have provided a technique to investigate these questions more closely. When the text display is removed during a specified saccade, the reader frequently can report the word to which the eyes are being sent. This finding suggests that the reader has

noticed or extracted some information from the periphery about the subsequently fixated word.

Fixation Duration Reflects Concurrent Processing

The fact that the durations of individual fixations vary with the characteristics of the stimulus being perceived on those fixations suggests that the place which a reader has fixated is the region of the text from which information extraction is taking place. To some extent these pauses of the eyes also reflect ongoing language processing at that point. The evidence to support this notion is only circumstantial. A specific fixation disruption occurring during reading has been observed in those cases when stimulus manipulations were made during that fixation (Wolverton, Note 8), and when erroneous information was present on that fixation (Rayner, 1975; Underwood, 1980). The current study demonstrates that the degree of constraint upon words also influences the duration of fixation upon the constrained word. Furthermore, regression analysis has been used to associate temporal increments with other textual variables in the analysis of eye movement data (Just & Carpenter, 1980; Hogaboam, Note 7). Thus, there is sufficient evidence to warrant the assumption that the durations of individual fixations reflect, to at least some degree, the processing stimulated by visual information noticed on a fixation. No evidence has as yet been reported that contradicts this perspective. It is conceivable that the information about the deviant letter strings present in the text of the current study was noticed or extracted on those fixations prior to the fixations upon which the effect was observed. Such

a position is still a tenable hypothesis, although much circumstantial evidence has been amassed as a counter point (McConkie, Note 6).

Units of Processing in Reading

The problem of perceptual units in reading has had a long and difficult history (Huey, 1908/1968), and is still far from being resolved. The current study seems to suggest that the letter is a unit of processing in that it is noticed even in highly redundant locations. Others have proposed a preliminary letter identification model for word recognition which suggests that a letter feature analysis is a logical precursor to letter and subsequent word identification (e.g., Johnston & McClelland, 1980). The data patterns of the current study show that words with spelling errors take longer to identify as a function of the degree of deviation. Replacing even a single letter in the center of a highly constrained word with its most visually similar letter, a substitution that causes only a minimal configuration distortion in the word, resulted in some disruption of the reading process when compared to the noerror control condition. In a related study, McConkie and Zola (1979) demonstrated that it is not strictly graphic information that is carried over from fixation to fixation, since the physical shapes of letters can be changed from one fixation to the next without any apparent detection of the change or without any detectable disruption of the reading process. This finding was confirmed and extended by Rayner, McConkie, and Zola (1980). Together these studies suggest that specific letter information is being noticed by the reader and that some abstraction of letter information is occurring

during the fixation upon which that information is noticed. Thus, at some very fundamental processing state in reading, abstract letter information is being used for the identification of the elements of the text. That is to say, skilled readers are responding to letters as units (Rayner, McConkie, & Ehrlich, 1978).

Limitations and Concerns

It is necessary to point out some limitations of this study.

Phrase length. First, the use of seven or eight letter words as the exclusive length of critical nouns and adjectives may provide an artificial assessment of the redundancy effect. Consider the phrase green grass. If the word green received a fixation, a pattern in the periphery would contain the word grass. If the passage was discussing a young man's summer job of mowing yards, and the noticeable peripheral pattern consisted of the first two letters and the last letter of the word grass, then the choice of the next word would be greatly restricted. In the current study, the length of the adjective-noun phrases would not have permitted such a detailed resolution of peripheral information. Thus, the word grass may not receive a foveal fixation and may be skipped over (i.e., may not receive a direct fixation). Therefore, further study using phrases with shorter word lengths is necessary to expand the story of the effect of redundancy on perception in reading

Noun selection. The use of seven or eight letter nouns as the exclusive length and class of the target words may also have produced a bias effect. Current eye movement research has shown that most relatively

long and substantive content words are fixated (Just & Carpenter, 1980; Rayner, 1979a; Rayner & McConkie, 1976). This fact suggests that the physical layout and the linguistic structure of the critical phrases used in the current study may have forced the subjects into directly fixating the target areas. Once the target locations were fixated, any erroneous orthographic information in letter string at those locations was noticed. However, this type of "ceiling effect" does not appear to be the only reason for the detection of deviance in the current study. The same result has been obtained using five letter words (Ehrlich & Rayner, personal communication).

Task instructions. Were the subjects really reading or were they looking for errors? Circumstantial information suggests that subjects did not adopt a search-for-deviance strategy. First and foremost was the design of the task. The misspelled words were never tested. There were only 8 misspellings in every 720 words and 4 of these involved only a single internal letter substitution. The readers were told that some words would be misspelled, but they should not worry about them since their task was to read the paragraphs for understanding and to be able to answer the comprehension questions correctly. This instructional strategy was found to be necessary since pilot subjects who were not told of errors in the text continually questioned the purpose of the misspellings. Furthermore, the reading rates for each individual subject across the passages were consistent with rates obtained on control passages that did not contain errors. The subjects also received a fair amount of practice at reading

text with spelling errors. Many texts encountered everyday, especially newspapers, contain errors of this type. Finally, after the final comprehension test, subjects were asked to predict words from the last 12 paragraphs read. This task indirectly sought a series of the words that were misspelled. From the subjects' responses, no obvious indication of focusing on the degraded spellings was evident. That is to say, subjects were unable to recall which specific words were incorrectly spelled in the last few paragraphs read.

Conclusion

The extracting of visual information from text is a fast and efficient process that involves the abstraction of relevant relational structure. This perceptual process relies most heavily upon the visual information afforded by the printed text (McConkie & Zola, 1981). Such a perspective is taken in opposition to many contemporary formulations of the reading process that suggest reading is only incidentally visual. The importance of visual detail information seems clear from the research reviewed here and the study reported. The major conclusions are three: (a) interword redundancy facilitates the perception of words, but does not appear to influence location of fixations within phrase units; (b) skilled readers depend upon visual detail information more heavily than is often suggested; and (c) letters are important to reading and are noticed when the visual detail information falls directly upon the foveal region. All of these findings emphasize the importance of relational structure among the printed units of prose.

Reading normally involves a stimulus that is not degraded in some manner, and looking to "see" what is present at some location seems more efficient than using knowledge of language constraints to calculate what is probably there. One area that is not clear at this time involves the acquisition of reading skill. Many reading curricula assume that the development of reading skill involves a reduction in the use of visual detail information. This point is also called into question, and requires future research.

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Appendix A

SAMPLE ADJECTIVE-NOUN PAIRS OF WORDS:

High Redundancy Category	Low Redundancy Category
SEARCH WARRANTS	NEEDED WARRANTS
BOMBING MISSION	ROUTINE MISSION
OPTICAL ILLUSION	CURIOUS ILLUSION
PARENTAL GUIDANCE	VALUABLE GUIDANCE
BOTANICAL GARDENS	BEAUTIFUL GARDENS
NATIONAL MONUMENT	SPLENDID MONUMENT
COMPOUND FRACTURE	TERRIBLE FRACTURE

Appendix B

SAN DIEGO IS THE FASTEST GROWING RESORT TOWN IN THE UNITED STATES. IT HAS MANY THINGS TO OFFER. THERE ARE BOTANICAL GARDENS THAT EXHIBIT VERY FINE COLLECTIONS OF PLANTS AND TREES. THERE IS ONE OF THE LARGEST AND MOST COMPLETE ZOOLOGICAL PARKS IN THE WORLD. THERE ARE MANY CULTURAL EVENTS HAPPENING EACH DAY. AND, OF COURSE, THERE IS THE PACIFIC OCEAN.

Footnotes

[1]Context also has a documented effect on the perception of scenes and objects (Biederman, 1972; Pachella, 1975; Palmer, 1975a), on the identification of categories (Rosch, 1973, 1975), and on the proofreading task (Crosland, 1924; Drewnowski & Healy, 1977).

[2]Normal reading is here taken to be a task in which a reader is primarily attempting to understand the meaning of a passage of connected discourse.

[3]Pattern distortion as a research paradigm to study the extraction process has a long history in reading related research (e.g., Allington & Strange, 1977; Huey, 1908/1968; Pillsbury, 1897; Rayner & Kaiser, 1975).

[4]A small group of phrases like blue sky and dark night appear with great regularity in children's reading materials.

[5]The raw data consisted of 1-msec samples of the location of the eyes. These samples were recorded continuously during the entire reading of each passage. Eye position was measured on a scale in which an eye movement of one-third of a degree of visual angle, i.e., the width of one letter position in the current experimental setup, corresponded to a change of approximately 40 values. A saccade was defined on the basis of the velocity of the movement and on the basis of changes in movement trends. Transitions in four successive data samples of 10 values, which corresponded to approximately 5 minutes of arc, were taken as indications of saccadic movement. A further search in the data stream for that particular point where the directional trend of the movement was broken

defined the exact data point where each saccade began or ended. A fixation was defined as the temporal duration between successive saccades. Its location was taken to be the position of the eyes halfway through the fixation interval. A simple linear interpolation model based upon a passage-specific calibration pattern was used to convert the fixation location value into character position information. Saccade size was defined as the distance between fixations.

[6]Previous research (Rayner, 1975) has indicated that information more than four letter positions to the left of the location of fixation is not being noticed or used during the current fixation. Underwood (1980) has recently collected some quizzical data which suggests that the previously specified limits of the asymmetry toward the left of the center of fixation may actually be underestimates of what he has found to be a very pronounced bias toward the right.

[7]A question of particular interest in this study became whether or not subjects noticed the minimal spelling degradation. To ensure that the great variability observed in other conditions (viz., DS3 and DS4) was not actually masking an interaction between the two principle factors in the control and minimal degraded spelling conditions, two Dunnett's test for comparisons involving control means (Kirk, 1968) were calculated. This procedure revealed significant difference for both the high- and low-redundancy conditions, HiR: $\underline{d}' = .033$, $\underline{p} < .05$; LoR: $\underline{d}' = .053$, $\underline{p} < .01$. In other words, even the most subtle violation of orthographic pattern caused significantly inflated fixation durations when the letter string in

the CNL was directly fixated. Thus, textual redundancy does not permit reduced dependence of visual feature extraction for words that are centered on the fovea.

[8]The asymmestry of the perceptual span (McConkie & Rayner, 1976b; Rayner, 1978; Underwood, 1980) suggests that, to some extent, the visual detail to the left of the center of fixation may not be noticed. The bias toward the right for the "pick up" of information in the reading of printed English text indicates the importance of attention. That is to say, the extraction of information from text for the purpose of reading must involve "ignoring" some information that is available on the fovea during fixations. Therefore, the statement that all the visual detail available during each foveal fixation is actually noticed may be an overstatement of fact.

Table 1

Instances of Data Elimination

Source	Experimental Conditions				
	C	DS1	DS2	DS3	DS4
High Redundancy					
Blinks before CNL	4	3	5	3	9
Blinks in CNL	3	3	4	2	7
Head movement artifacts	53	64	57	57	57
Low Redundancy					
Blinks before CNL	3	5	2	3	16
Blinks in CNL	0	2	0	1	13
Head movement artifacts	60	53	55	54	45

Table 2

Percent of Time Critical Words Fixated

Word Category	Experimental Conditions				
	C	DS1	DS2	DS3	DS4
Critical Adjective Location					
High redundancy	.94	.94	.95	.96	.96
Low redundancy	.97	.98	.98	.97	.99
Critical Noun Location					
High redundancy	.98	.95	.99	.98	.99
Low redundancy	.95	.96	.99	.99	1.00

Table 3

Summary of Various Eye Movement Dependent Variables

Experimental Conditions		Global Analysis of Temporal Characteristics		Initial Fixation of TPL				Initial Fixation of 4th Letter of TPL			
Redundancy Level	Degraded Spelling Level	Mean Line Reading Time (msec)	Mean Aggregated Time on CNL (msec)	Mean Fix. Dur. on CAL (msec)	Mean Sac. Len to CNL (Char Pos)	Mean Fix. Dur. on CNL (msec)	Mean Saccade Leaving CNL (Char Pos)	Mean Fix. Dur. on CAL (msec)	Mean Sac. Len. to CNL (Char Pos)	Mean Fix. Dur. on CNL (msec)	Mean Sac. Len Leaving CNL (Char Pos)
HiR	Control	2852	290	2[illegible]	8.5	220	9.8	236	8.2	221	10.0
	DS1	2978	353	233	8.4	244	9.3	236	8.3	248*	9.1
	DS2	2997	351	248	8.9	236	9.6	242	9.0	246*	9.7
	DS3	3069	479*	244	7.8*	259*	8.9*	243	7.9	275*	8.6*
	DS4	4032*	971*	234	6.6*	317*	7.5*	226	6.4*	310*	7.3*
	sd Range	782-1315	75-542	35-50	1.1-2.0	27-82	1.8-2.7	36-68	1.3-2.3	34-98	1.7-2.8
LoR	Control	2860	313	237	8.8	243	9.3	238	8.7	237	9.2
	DS1	3103	396	231	8.4	249	9.2	235	8.4	266*	9.5
	DS2	3265	406	248	8.6	277	9.1	282	7.9	275*	8.6
	DS3	3425*	576*	240	7.5*	283*	8.4*	242	7.5	305*	8.2*
	DS4	4432*	1095*	259	6.7*	316*	7.0*	245	5.7*	328*	7.1*
	sd Range	771-1480	75-681	37-52	1.1-2.4	50-68	1.7-2.5	48-112	1.6-2.6	58-86	1.6-2.8

Note. Degraded Spelling (DS)

Critical Adjective Location (CAL)

Critical Noun Location (CNL)

Target Phrase Location (TPL)

*The difference between experiment and control condition achieved statistical significance.

Figure Captions

Figure 1. Examples of the various types of degraded spellings (DSn) used in this experiment. The misspelled letter strings were substituted for the nouns in the target adjective-noun phrases.

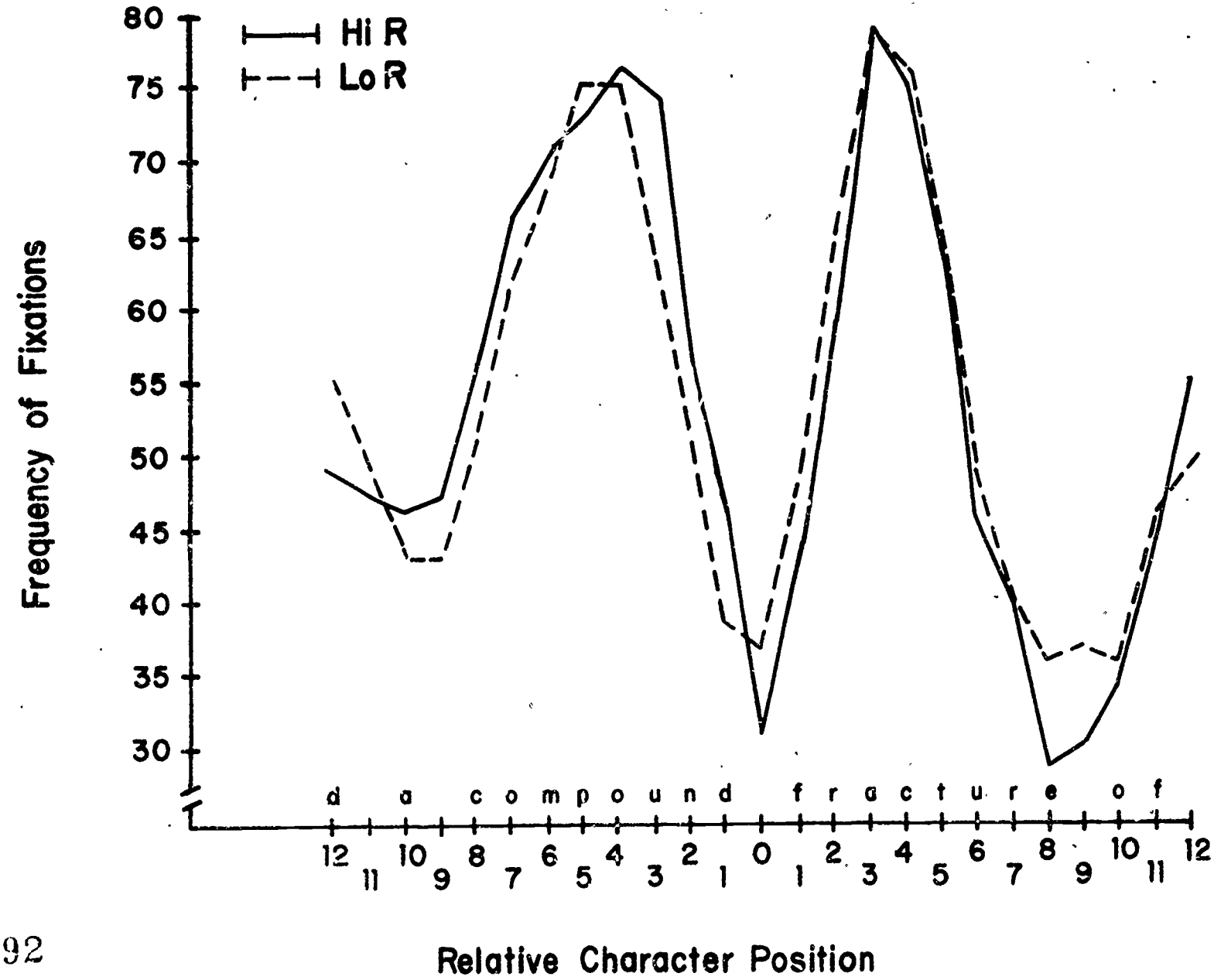
Figure 2. Number of fixations at each relative character position for the high- and low-redundancy conditions with no spelling degradations. The segment of a sample line of text is printed on the horizontal axis to show the relationship of the relative character positions and the target adjective-noun phrases.

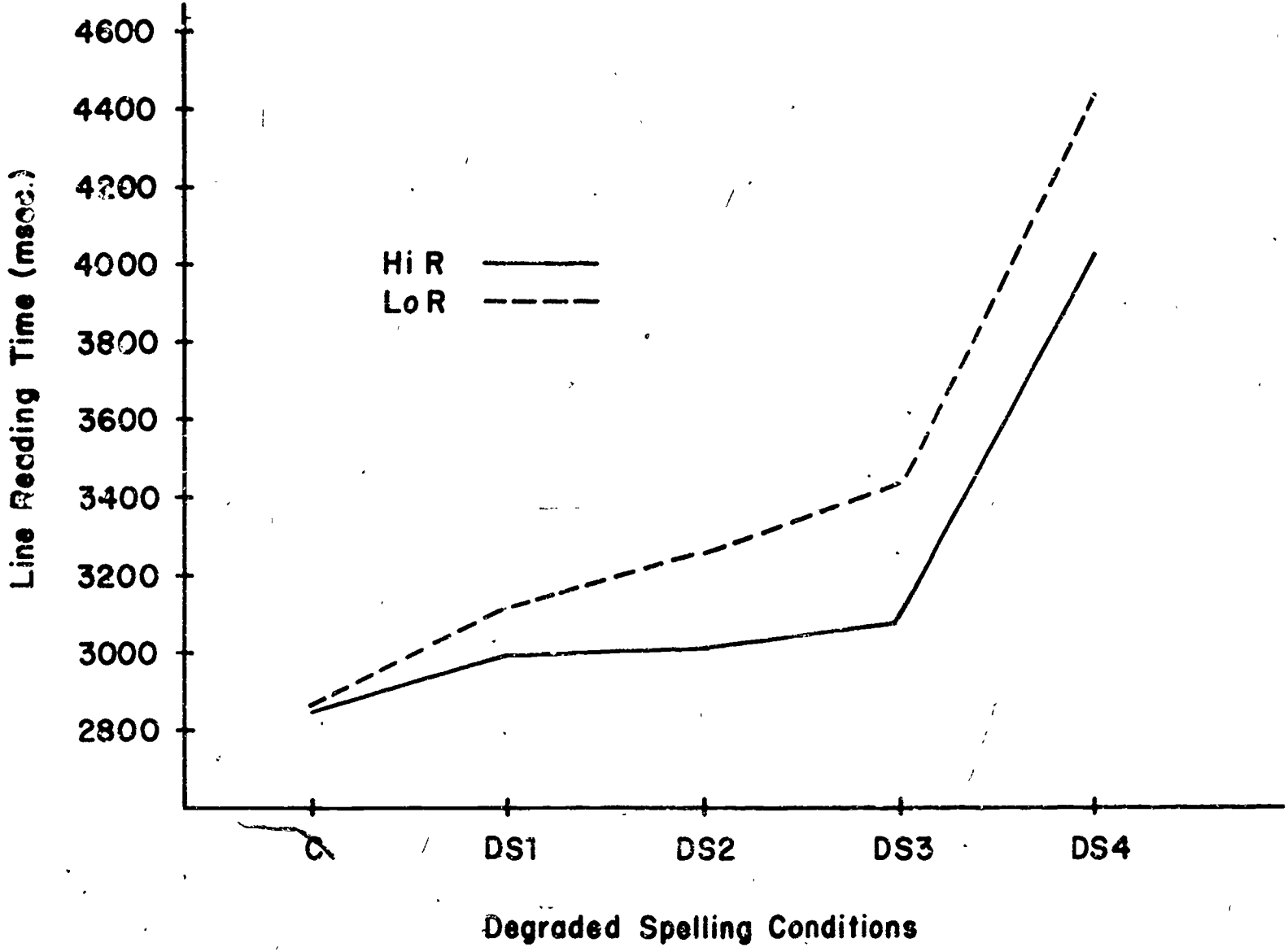
Figure 3. Effects of the experimental variables on Line Reading Time (LRT).

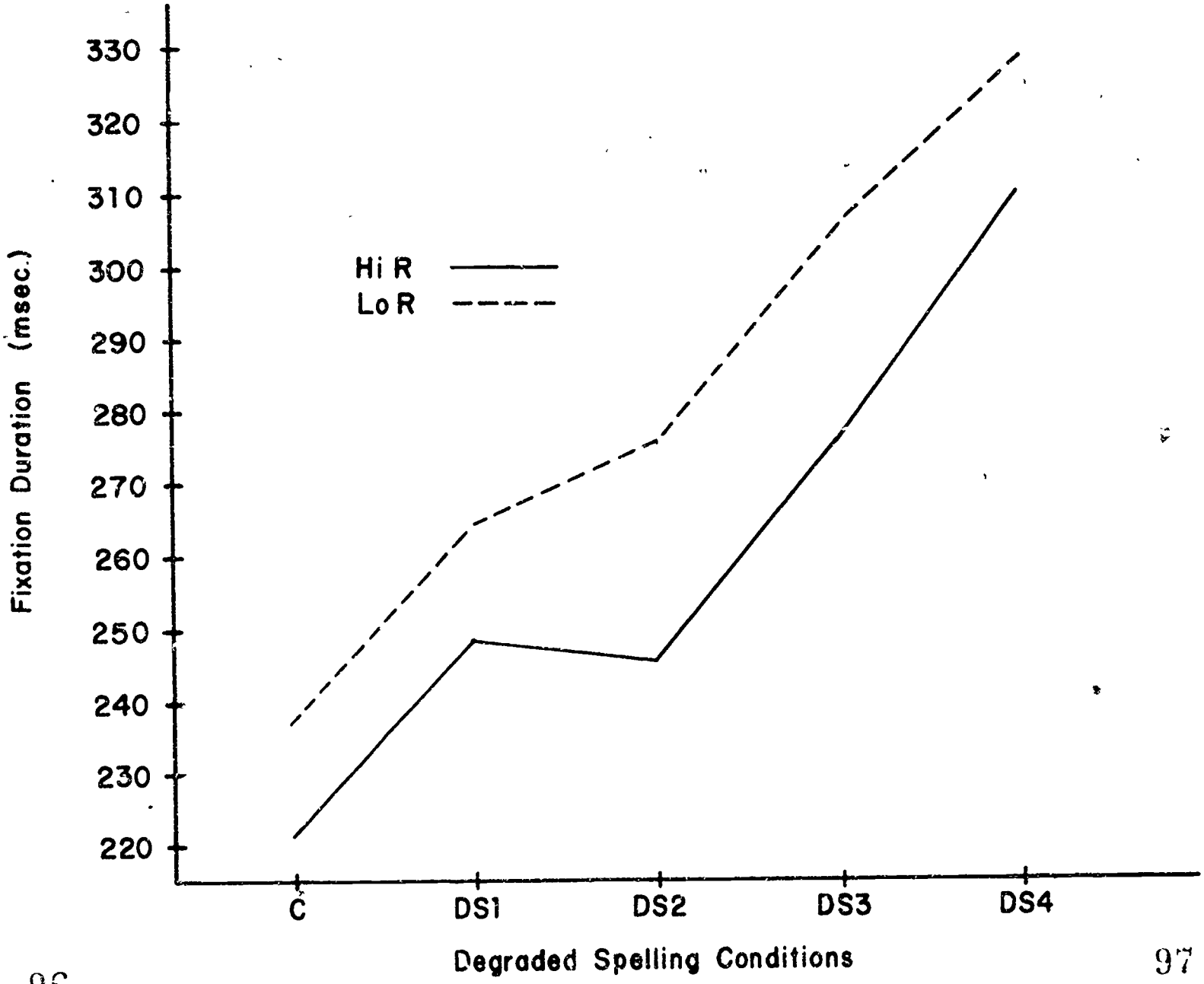
Figure 4. Effects of the experimental variables on fixation durations located on the middle region of the target nouns.

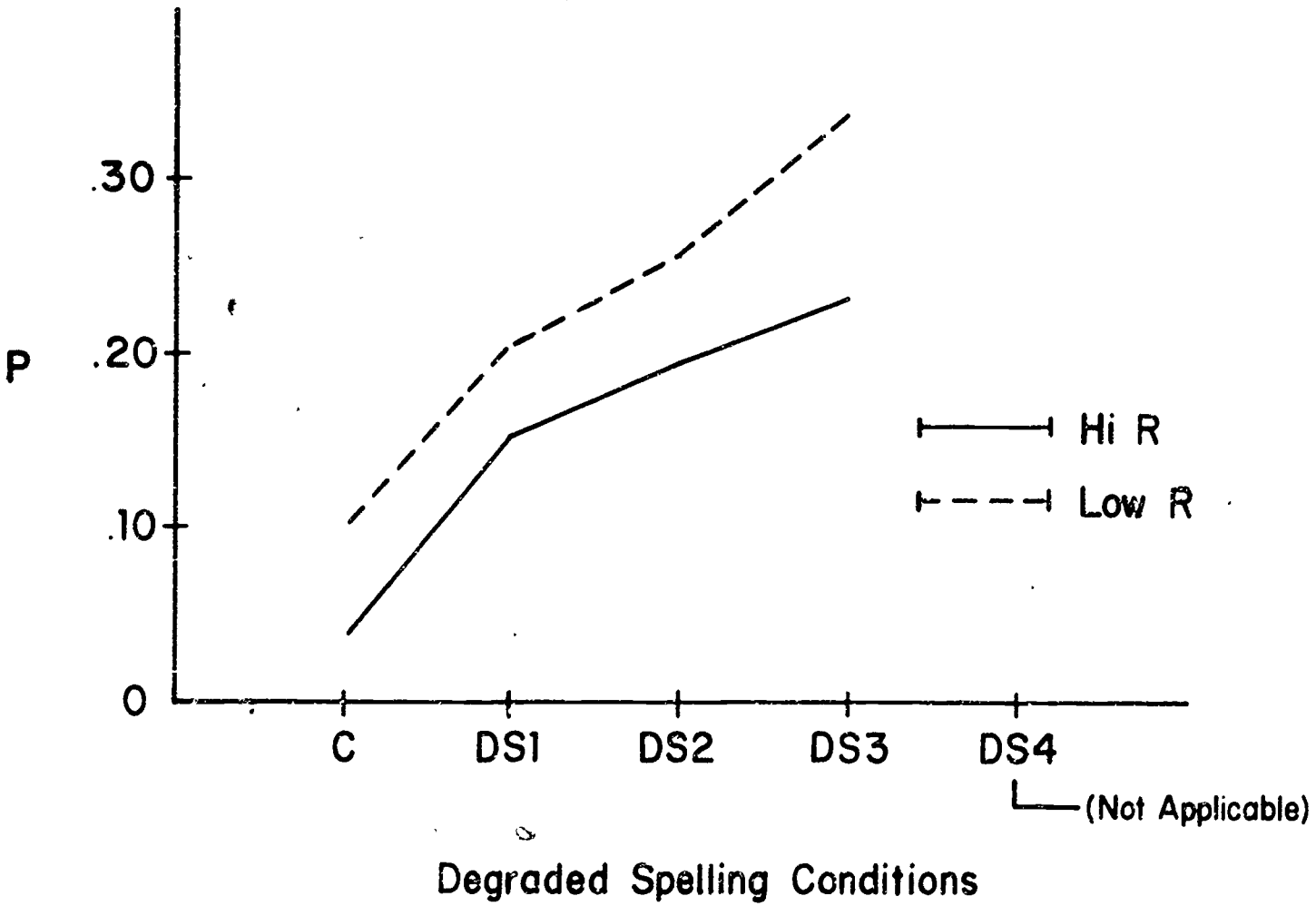
Figure 5. Effects of the experimental variables on the probability of regressing to the target nouns.

Conditions	Letter String
Control	gardens
DS1	garbens
DS2	garfens
DS3	garbhns
DS4	darfenj


Hi R
Lo R
Frequency of Fixations
80
75
70
65
60
55
50
45
40
35
30
d a c o m p o u n d f r a c t u r e o f
12 11 10 9 8 7 6 5 4 3 2 1 0 1 2 3 4 5 6 7 8 9 10 11 12
Relative Character Position


4600
4400
4200
4000
3800
3600
3400
3200
3000
2800
Line Reading Time (msec.)
Hi R
Lo R
C
DS1
DS2
DS3
DS4
Degraded Spelling Conditions


330
320
310
300
290
280
270
260
250
240
230
220
Fixation Duration (msec.)
Hi R
Lo R
C
DS1
DS2
DS3
DS4
Degraded Spelling Conditions


P
.30
.20
.10
0
C
DS1
DS2
DS3
DS4
(Not Applicable)
Hi R
Low R
Degraded Spelling Conditions

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